Table 4-39. Detection rates of tritium in the sampled media.

Media	Detection Rate	Range of Detected Values (pCi/L)	Total Number of Detections Greater than the Maximum Contaminant Level (20,000 pCi/L)
Soil moisture: 0 to 35 ft	39.2	129 to 9,100	22
Soil moisture: 35 to 140 ft	37.5	1,680 to 2,950	0
Soil moisture: greater than 140 ft	13.3	169 to 1570	0
Aquifer-Idaho National Engineering and Environmental Laboratory	37.6	398 to 2600	0
Aquifer-U.S. Geological Survey	33.7	700 to 5400	0

4.6.8 Iodine-129

Iodine-I29 is a radioisotope that is produced from nuclear reactor operations and weapons testing. It also is produced in the environment in extremely low concentrations by interactions of cosmic rays with gases in the atmosphere, and from the spontaneous fission of naturally occurring U-238 (Mann and Beasley 1994). It decays by the emission of beta particles, has a 1.57E+07 year half-life, and was identified in the **IRA** as a COPC, primarily for the groundwater ingestion exposure pathway (Becker et al. 1998).

Iodine-129-bearing waste in the SDA and the available 1-129 monitoring data for all media are summarized below. The sampling data in this section are evaluated against the comparison concentrations in Table 4-40.

Table 4-40. Comparison concentrations for iodine-129 in groundwater and soils.

Surface Soil Background Concentration (pCi/g)	Risk-Based **Soil** Concentration[a] (pCi/g)	Aquifer Background Concentration (pCi/L)[b]	Maximum Contaminant Levels (pCi/L)	Risk-Based Aquifer Concentration[b] (pCi/L)
Not established	29.3	0	1	3.2

a. Calculated risk-based concentration equivalent to an increased cancer **risk** of **1E-05** (Knobel, Orr, and Cecil 1992).

4.6.8.1 Waste Zone. Approximately 0.15 Ci of 1-129 were disposed of in the SDA. Table 4-41 identifies the waste streams containing the majority of I-129 activity. Gamma spectral logging data provide no information regarding 1-129.

4.6.8.2 Surface. No surface data are available for 1-129 because it has not been a target analyte for surface monitoring.

4.6.8.3 Vadose Zone. The distributions of 1-129 in vadose zone core, soil moisture, and perched water in the various depth intervals are discussed below.

Table 4-41. Waste streams containing iodine-129.

Waste Stream Code or Generator	Waste Stream Description	Activity (Ci)	Proportion of Total Activity (%)
Idaho National Engineering and Environmental Laboratory (INEEL)	INEEL reactor operations waste	1.49E-01	94.5
Naval Reactors Facility	Test specimens	2.67E-03	1.7
PBF-620-1	Miscellaneous scrap	1.90E-03	1.2
Total Disposals		1.58E-01	100

4.6.8.3.1 *Vadose Zone Core Samples*—A total of 52 core samples were analyzed for I-129 between 1994 and 2000, with no positive detections. Samples were collected between 1994 and 2000 from the following SDA boreholes: I-1S, I-ID, I-2S, I-2D, I3S, I4D, US, O-1S, O-1D, O-2S, O-2D, O-3S, O-3D, 2E, 3E, 4E, 5E, 3V, 4V, 5V, 6V, 7V, 8V, 9V, and 10V. Previous core sampling investigations (1971 to 1993) did not analyze for I-129, as it was not a radionuclide of principal concern at that time. The distribution of samples in the various depth intervals is summarized in Table 4-42.

Table 4-42. Distribution of vadose zone core samples for iodine-129 analyses.

Depth Interval (ft)	Number of 1-129 Detections/ Number of Cores Sampled	Detection Rate (%)	Cores with Detections
0 to 35	0/11	0	None
35 to 140	0/25	0	None
140 to 250	W16	0	None
Greater than 250	0/0	Not applicable	None

4.6.8.3.2 *Lysimeter Samples at Depths of 0 to 35 ft*—A total of 59 shallow lysimeter samples were analyzed by INEEL for 1-129 between 1997 and September 2000, with three positive detections (see Table 4-43).

Table 4-43. Detected concentrations of iodine-129 in the shallow vadose zone lysimeters.

Lysimeter	Depth (ft)	Concentration ± 1σ (pCi/L)	Confirmation Flag'	Date
98-1L35 (SDA-01)	16.5	**53 ± 18**	A	November 1998
98-5L39 (SDA-10)	17.0	**29 ± 6**	A	December 1998
W25-L28	15.5	**22 ± 7**	A	June 2000

a. Continnation flag:
A = No second sample collected, no reanalysis performed.
Note: Values in **red bold** indicate that the concentration exceeds the maximum contaminant level (MCL) of 1 pCi/L. The maximum contaminant level for the aquifer does not apply to soil moisture samples, but are used here as a basis of comparison.

Despite the relatively high concentrations of I-129 in the lysimeter samples, the 1-129 detections occur only sporadically. Figure 4-26 shows the occurrences of the 1-129 detections. None of the positive sample results could be supported by reanalysis of the original sample. Subsequent samples collected from these lysimeter wells through September 2000 have not shown detectable 1-129. There are no spatial trends to the I-129 detections. The lysimeter wells are located some distance from each other, not clustered.

***4.6.8.3.3 Lysimeter Samples at Depths of 35 to 140 ft*—A** total of seven samples from three lysimeters were analyzed by INEEL for 1-129 between 1997 and November 1998, with no positive detections. The other lysimeter wells in this depth interval were not analyzed for 1-129 because the volume of water collected from them was insufficient to perform the analysis.

4.6.8.3.4 Perched Water Samples at Depths Greater than 140 ft—A total of nine water samples and 10 filtered sediment samples from the perched water wells (USGS-92 and 8802D) were analyzed by INEEL for I-129 between 1997 and November 1999. No positive detections of 1-129 were identified. Because of the limited sample volumes, the detection sensitivity is not adequate for comparison to the drinking water MCL of 1 pCi/L. No data are available for the deep lysimeter well samples because the volume of water collected was insufficient to perform the analysis. The USGS does not analyze samples from Well USGS-92 for I-129.

4.6.8.4 Aquifer. **A** total of 242 RWMC aquifer well samples were analyzed by INEEL for 1-129 between 1994 and April 2001. Five positive detections were identified in more than 20 sampling campaigns (see Table **4-44)**. Aquifer Well M1S was the only well with more than one 1-129 detection and one of the detections was unusually high. Samples collected in aquifer Well M1S during the 11 sampling events since the last detection have contained undetectable levels of 1-129.

The July 1998 sample from M1S was reanalyzed but the result was a nondetect. The other samples with positive detections were not reanalyzed. Three of the sample results exceeded the MCL of 1 pCi/L (i.e., aquifer Wells MIS, M7S, and MIOS). These exceedances were one-time detections.

Following routine sample collection in September 1996, seven 1-129 results were reported as positive. On closer evaluation of the data package, it was discovered that 1-129 also was detected in the corresponding field blank at a concentration equivalent to the sample results (3.7 ± 0.3 pCi/L). Results from the aquifer wells sampled in this campaign (i.e., M1S, M3S, M4D, **M6S,** and M10S) were declared false positives. The September 1996 data were revalidated and the revised limitations and validation report reissued to DOE-ID (see footnote a, p. 4-52). No USGS 1-129 data are available for comparison because the USGS does not analyze for 1-129 in their eight RWMC wells.

The radioanalytical detection sensitivity for 1-129 is about the same as its MCL (1 pCi/L), so trends cannot be identified before the concentration actually exceeds the MCLs. **A** radioanalytical laboratory that can achieve lower 1-129 detection sensitivities (e.g., 10 times lower than the MCL [0.1 pCi/L]) is being identified through the INEEL monitoring program. Future INEEL aquifer well samples will be sent to this radioanalytical laboratory for low-level I-129 analyses.

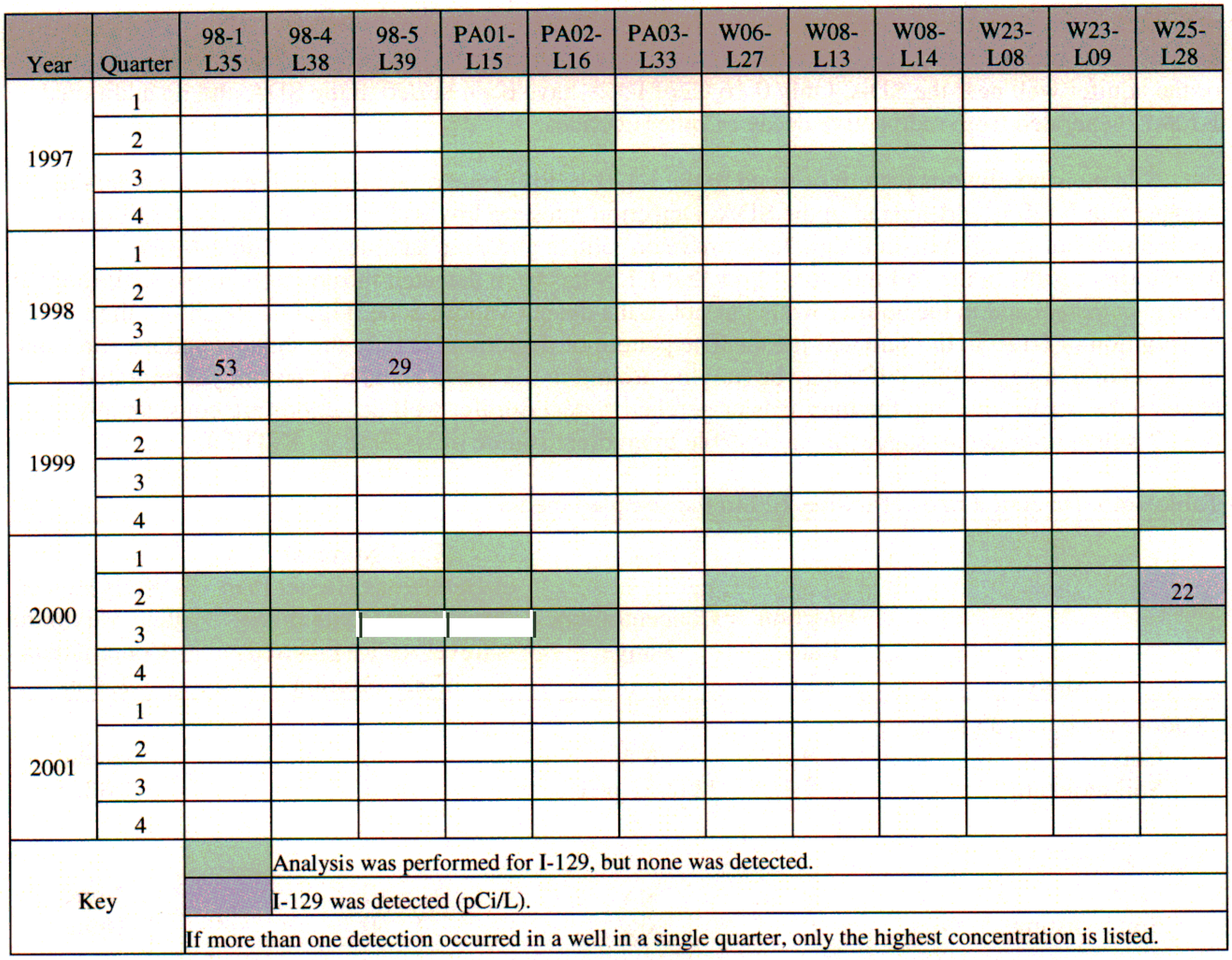

Figure 4-26. Occurrences of iodine-129 detections in shallow lysimeter wells.

Table 4-44. Positive detections of iodine-129 in aquifer.

Aquifer Well	Concentration ± 1σ (pCi/L)	Confirmation Flag[a]	Date
M1S	**17.0 ± 1.5**	A	April 1996
	1.0 ± 0.2	B	July 1998
M6S	0.59 ± 0.17	A	October 1997
M7S	**1.5 ± 0.4**	A	October 1998
M10S	**1.7 ± 0.4**	A	April 1997

a. Confirmation flag:
A = No second sample collected, no reanalysis performed
B = Reanalysis performed, no confirmation

Note: Values in **red bold** indicate that the concentration exceeds the aquifer maximum contaminant level of 1 pCi/L.

***4.6.8.5 Summary* of Iodine-129.** Because of its high mobility and toxicity, 1-129 is a risk driver; however, the monitoring data to date do not present a clear picture of 1-129 occurrence in the vadose zone or the aquifer well near the SDA. Only 0.16 Ci of 1-129 have been buried in the SDA and no additional I-129 is generated from radioactive decay of other nuclides.

There is no obvious pattern or trend to the I-129 vadose zone or aquifer well monitoring data to suggest that 1-129 is widespread in the SDA. Detection rates are low with no detections of 1-129 in the core samples or in soil moisture samples from intermediate and deep samples (see Table 4-45). Monitoring results in the soil moisture show that 1-129 has been detected infrequently in the shallow (0 to 35 ft) lysimeters and in the aquifer wells but not in the deeper vadose zone. Figure 4-27 shows the distribution of 1-129 in the sampled media. The pattern of detections in only the shallow vadose zone and in the aquifer suggests that I-129 may be moving around in the waste zone, but has not yet migrated beneath the waste zone into the interbeds or perched water. Aquifer well detections are considerably (i.e., 2 miles) upgradient, suggesting a possible upgradient source of 1-129 (e.g., INTEC).

Table 4-45. Detection rates of iodine-129 in the sampled media.

Media	Detection Rate (%)	Concentration Range	Total Number of Detections Higher than Maximum Contaminant Level[a] or Risk-Based Concentration[a]	Wells Higher than Maximum Contaminant Level
Vadose zone 0 to 35 ft:				
Cores	0	NA	0	None
Soil moisture	5.1	22 to 53 pCi/L	3	None
Vadose zone 35 to 140 ft:				
Cores	0	NA	0	None
Soil moisture	0	NA	0	None
Vadose zone >140 ft:				
Cores	0	NA	0	None
Soil moisture	0	NA	0	None
Aquifer	2.1	0.59 to 17.0 pCi/L	3	M1S, M7S, MlOS

a. The concentrations for cores are compared to the risk-based concentration of 29.9 pCi/g. The soil moisture and aquifer results are compared to the maximum contaminant level of 1 pCi/L. The maximum contaminant level does not apply to soil moisture data but is used here as a basis of comparison.

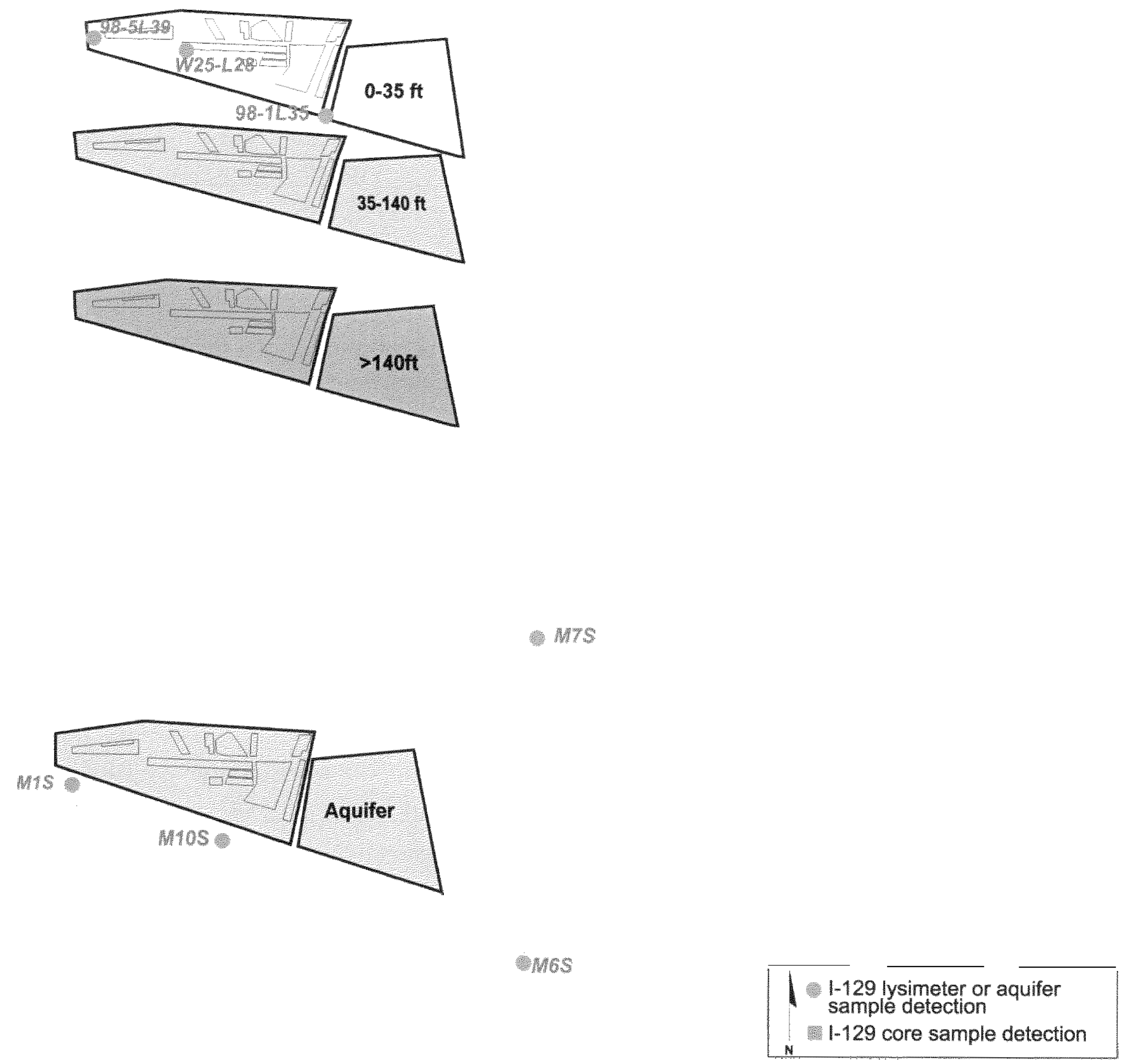

Figure 4-27. Locations where iodine-129 was detected in lysimeter and well samples.

4.6.9 Niobium-94

Niobium-94 is a radioisotope that is an activation product produced by nuclear reactor operations. It decays by the emission of beta particles and gamma rays, has a half-life of 2.0E+06 years and was identified in the IRA as a COPC, primarily for the external exposure and groundwater ingestion pathway (Becker et al. 1998).

Niobium-94-bearing waste in the SDA and the available Nb-94 monitoring data for all media are summarized below. The sampling data in this section are evaluated against the comparison concentrations in Table 4-46.

Table 4-46. Comparison concentrations for niobium-94 in groundwater and soils.

Surface Soil Background Concentration	Risk-Based Soil Concentration[a] (pCi/g)	Aquifer Background Concentration	Maximum Contaminant Level (pCi/L)	Risk-Based Aquifer Concentration[a] (pCi/L)
Not established	387	Not established	1,070	61.3

a. Calculated risk-based concentration equivalent to an increased cancer risk of 1E-05.

No aquifer or lysimeter well data for Nb-94 are identified because it is not a routine target analyte. However, it would have been detected and reported if concentrations were observed above the gamma-analysis detection limit.

The calculated MCL for Nb-94 is 1,070 pCi/L based on a dose of 4 mrem/year (40 CFR 141.16). Therefore, the gamma detection sensitivity would be more than adequate for detecting Nb-94.

4.6.9.1 Waste Zone. Approximately 1,000 Ci of Nb-94 were disposed of in the SDA. Table 4-47 identifies the waste streams containing the majority of Nb-94 activity. Gamma spectral logging data provide no information about Nb-94.

Table 4-47. Waste streams containing niobium-94.

Waste Stream Code or Generator	Waste Stream Description	Activity (Ci)	Proportion of Total Activity (%)
Idaho National Engineering and Environmental Laboratory (INEEL)	INEEL reactor operations waste	8.80E+02	87.6
CPP-603-1H	Fuel end pieces	4.74E+01	4.7
Test Reactor Area	Activation products	4.06E+01	4.0
Miscellaneous	Miscellaneous minor streams	2.31E+01	2.3
NRF-618-12H	Core structural components	1.31E+01	1.3
Total Disposals		1.00E+03	100

4.6.9.2 Surface. No surface sample data are available because Nb-94 has not been a target analyte for monitoring.

4.6.9.3 Vadose Zone. No gamma spectrometric analytic results are available for Nb-94 in vadose zone core samples because Nb-94 was not a target analyte. Though **not** a target analyte, Nb-94 would have been detected and reported if concentrations were observed above the gamma spectrometric analysis detection limit (<0.1 pCi/g) in routine gamma analysis. No detections were reported from vadose zone core analyses, suggesting that the gamma analysis did not detect Nb-94 higher than 0.1 pCi/g.

Niobium-94 was not a target analyte in the lysimeter samples but would have been reported had it been detected above the contract-required detection limit for gamma-emitting radionuclides (<200 pCi/L). No reportable quantities of Nb-94 were detected in the lysimeter samples.

4.6.9.4 Aquifer. No aquifer well gamma spectrometric analytic results are available for Nb-94 because no analyses were performed. If concentrations of Nb-94 above the gamma-analysis detection limit had been observed, Nb-94 would have been included in the laboratory report. The contract-required detection limit for gamma-emitting radionuclides in aquifer samples using gamma spectrometric analysis is 30 pCi/L. The analytical laboratories routinely achieve the minimum detectable activities between 3 and 10 pCi/L in aquifer samples. No detection levels of gamma-emitting radionuclides were reported.

4.6.9.5 Summary of Niobium-94. The data are inadequate to assess the distribution and occurrence of Nb-94 in the vadose zone. Indirect measurements by gamma spectrometric analytic results obtained on groundwater samples suggest that Nb-94 is not present in the aquifer.

4.6.10 Neptunium-237

Neptunium-237 is an anthropic, transuranic radioisotope that is a decay product of Am-241. It is produced by nuclear reactor operations, decays by the emission of alpha particles, and has a half-life of 2.14E+06 years. Neptunium-237 was identified in the IRA as a COPC, primarily for the groundwater ingestion exposure pathway (Becker et al. 1998).

Neptunium-237-bearing waste in the SDA and the available Np-237 monitoring data for all media are summarized below. The sampling data in this section are evaluated against the comparison concentrations in Table 4-48.

Table 4-48. Comparison concentrations for neptunium-237.

Surface Soil Background	Risk-Based soil Concentration[a] (pCi/g)	Aquifer Background Concentration	Maximum Contaminant Level (pCi/L)	Risk-Based Aquifer Concentration[a] Aquifer 1E-05 (p/Ci/L)
Not established	49.0	Not established	15 (total alpha)	7.1

a. Calculated risk-based concentration equivalent to an increased cancer risk of 1E-05.

4.6.10.1 Waste Zone. Approximately 2.6 Ci of Np-237 were disposed of in the SDA. Table 4-49 identifies the waste streams containing the majority of Np-237 activity.

Additional quantities of Np-237 are also produced over time through ingrowth (see Section 4.1.2). Table 4-49 includes the amount of Np-237 that would be produced if al of the parent decays. Percentages of the total Np-237 from the parent isotopes are not given because the amount of Np-237 present is dependant on the timeframe assessed. The decay of Np-237 will produce U-233 and Th-229.

The spectral gamma moisture logging tool detected Np-237 based on the 312 keV gamma rays from the daughter product, Pa-233. Of the 135 probeholes logged using this tool, 57 (42%) showed the presence of Pa-233 above the noise level. Of the 4863 total measurements (i.e., all probes and all depths), 511 (11%) showed the presence of Pa-233 above the noise level. The Pa-233 detection limit was approximately 1.7 pCi/g. The maximum and average observed Pa-233 levels were 141 and 5.3 pCi/g, respectively. The detection limit, maximum and average concentrations are based on the assumption that Pa-233 is uniformly distributed in the vicinity of the measurement points.

Table 4-49. Waste streams containing neptunium-237.

Waste Stream Code or Generator	Waste Stream Description	Activity (Ci)	Proportion of Total Activity (%)
Idaho National Engineering and Environmental Laboratory (INEEL)	INEEL reactor operations waste	7.54E-01	28.5
TRA-603-15H	Metal	6.85E-01	25.9
TRA-603-1H	Resins	4.13E-01	15.6
TRA-642-6H	Core, vessel and loop components	3.96E-01	15.0
TRA-603-4H	Core and loop components	1.74E-01	6.6
TRA-603-9H	Expended fuel and ceramic fuel	1.22E-01	4.6
Miscellaneous	Miscellaneous minor streams	6.61E-02	2.5
TRA-632-1H	Core structural pieces	3.42E-02	1.3
Total Disposals		2.64E+00	100
Am-241 ingrowth	Half-life equals 432 years. See Section 4.6.2	3.69E+01	NA
Pu-241 ingrowth	Half-life equals 14.4 years See Section 4.6.13	6.56E+00	NA

4.6.10.2 Surface. No surface data are available because Np-237 has not been a target analyte for surface monitoring.

4.6.10.3 Vadose Zone. The distributions of Np-237 in vadose zone core, soil moisture, and perched water in the various depth intervals are discussed below.

4.6.10.3.1 Vadose Zone Core Samples—No vadose zone core sample gamma spectrometric analytic results are available for Np-237. In previous subsurface sample evaluations (1971 to 2000), Np-237 was not considered a radionuclide of concern. However, in the 1998 IRA, it was identified as a COPC though it has not been included on the radionuclide target list provided to the analytical laboratories subcontracted to the INEEL. Neptunium-237 is now identified as a COPC and has been included on the radionuclide target list provided to the analytic laboratories.

4.6.10.3.2 Lysimeter Samples at Depths of 0 to 35 ft—A total of 28 shallow lysimeter samples were analyzed by INEEL for Np-237 between June 2000 (when Np-237 monitoring began) and May 2001, with no positive detections in any of the 12 INEEL shallow lysimeter wells.

4.6.10.3.3 Lysimeter Samples at Depths of 35 to 140 ft—No positive detections of Np-237 were identified in the 15 samples analyzed from the 35 to 140-ft interval of the vadose zone between June 2000 and May 2001.

4.6.10.3.4 Lysimeter and Perched Water Samples at Depths Greater than 140 ft—A total of five Np-237 analyses were performed on perched water and deep suction lysimeter well samples, with no positive detections. No data are available for perched water samples from Well 8802D because the volume of water collected was insufficient to perform Np-237 analysis. Also, the laboratory was unable to obtain sediment samples from the USGS-92 perched water well sample. The USGS does not analyze perched water from Well USGS-92 for Np-237.

4.6.10.4 Aquifer. A total of 150 samples from 15 INEEL wells were analyzed by INEEL for Np-237 between 1998 and April 2001, with no positive detections. The USGS does not analyze for Np-237 in the eight RWMC wells they manage, control, and routinely sample.

4.6.10.5 Summary of Neptunium-237. Only 2.6 Ci of Np-237 were disposed of in the SDA, but substantially more are expected to be generated in the waste from the decay of Pu-241 and Am-241. Given the increased inventory associated with ingrowth and the relatively high mobility of Np-237, Np-237 is a risk driver. Neptunium-237 has been detected in the waste zone with the spectral gamma moisture logging tool but has not been detected in any of the nearly 200 samples collected in the vadose zone or aquifer wells (see Table 4-50). No evidence indicates that Np-237 has migrated outside of the SDA.

Table 4-50. Detection rate for neptunium-237 in various media.

Media	Detection Rate	Range of Detected Concentrations	Total Number of Detections Higher than the Maximum Contaminant Level[a]	Wells Higher than Maximum Contaminant Level[a]
Source	Cores: 42% Measurements: 11%		0	None
Cores	0	0	0	None
Soil moisture: 0 to 35 ft	0	0	0	None
Soil moisture: 35 to 140 ft	0	0	0	None
Soil moisture: >140 ft	0	0	0	None
Aquifer	0	0	0	None

4.6.11 Protactinium-231

Protactinium-231 is an anthropic radioisotope that is a decay product of U-235. It is produced by nuclear reactor operations, decays by the emission of alpha particles, and has a half-life of 3.28E+04 years. It was identified in the IRA as a COPC, primarily for the groundwater ingestion exposure pathway (Becker et al. 1998).

Protactinium-231 is not a target analyte for monitoring but its presence can be inferred if its parent radionuclide (i.e., U-235) is detected.

4.6.17.7 Waste Zone. Negligible amounts (i.e., 8.64E-04 Ci) of Pa-231 were disposed of in the SDA as identified in Table 4-51. Additional quantities of Pa-231 are being generated over time through ingrowth (see Section 4.1.2). Table 4-51 also includes the amount of Pa-231 that would be produced if all of the parent decayed. Because of the long half-lives of the parent nuclides, it will be many thousands of years before substantial ingrowth occurs. However, for completeness, the waste streams that contain parent nuclides are listed in Table 4-51. Percentages of the total Pa-231 from parent isotopes are not given because the amount of Pa-231 present is dependant on the timeframe assessed.

Gamma spectral logging data were not analyzed for Pa-231.

Table 4-5 1. Waste streams containing protactinium-23 1.

Waste Stream Code or Generator	Waste Stream Description	Activity (Ci)	Proportion of Total Activity (%)
D&D-ARA- 1	Low-level waste from the decontamination and demolition of the Advanced Reactor Area facilities. Waste stream consists primarily of contaminated metal and debris.	8.56E-04	99
Miscellaneous	Miscellaneous minor streams.	8.44E-06	1
Total Disposals		8.64E-04	100
U-235 ingrowth	Half-life equals 7.04E+08 years. See Section 4.6.19	1.05E+05	NA
Pu-239 ingrowth	Half-life equals 2.41E+04 years. See Section 4.6.13	4.19E+04	NA
Am-243 ingrowth	Half-life equals 7.38E+03 years. See Section 4.6.3	2.66E+01	NA

4.6.1 7.2 Summary of Protactinium-237. There are no analytical data for Pa-23 1 because it is not a target analyte for environmental monitoring. However, its presence can be inferred by positive detections of U-235.

4.6.12 Lead-210

Though Pb-210 is the terminating radioisotope in the naturally occurring U-238 decay chain, its natural abundance is so small it is assumed to be zero. Therefore, Pb-210 in the environment should be considered anthropic. Lead-2 10 decays by the emission of beta particles with a half-life of 22.6 years. Lead-210 was identified in the IRA as a COPC, primarily for the soil and crop ingestion pathway (Becker et al. 1998).

Lead-210-bearing waste streams in the SDA are summarized below. Lead-210 is not a target analyte for monitoring but its presence can be inferred if its parent radionuclide (i.e., U-238) is detected.

4.6.12.1 Waste Zone. Approximately 5.1E-07 Ci of Pb-210 were disposed of in the SDA. Table 4-52 identifies the waste streams containing the majority of Pb-210 activity.

Additional quantities of Pb-210 are being generated over time through ingrowth (see Section 4.1.2) Table 4-52 also includes the amount of Pb-210 that would be produced if all of the parent decayed. Because of the long half-lives of the parent nuclides, it will be many thousands of years before substantial ingrowth occurs. However, for completeness, the waste streams that contain parent nuclides are also listed in Table 4-52. Percentages of the total Pb-210 from parent isotopes are not given because the amount of Pb-2 10 present is dependant on the timeframe assessed.

4.6.12.2 Summary of Lead-210. No analytical data are available for Pb-210 because it is not a target analyte for environmental monitoring. The presence of Pb-2 10 can be inferred by positive detections of U-238.

Table 4-52. Waste streams containing lead-210.

Waste Stream Code or Generator	Waste Stream Description	Activity (Ci)	Proportion of Total Activity (%)
ALE-ALE-1H	Building rubble, electric wires, piping, machinery, tracers and sources, glass, gloves, paper, filters, and vermiculite.	4.83E-07	94.7
WER-CMP-1	Compacted waste-combination of glass, plastic, absorbents, cloth, paper, and wood.	2.70E-08	5.3
Total Disposals		5.10E-07	100
U-238 ingrowth	Half-life equals 4.47E+09 years. See Section 4.6.19	2.35E+10	NA
U-234 ingrowth	Half-life equals 2.45E+05 years. See Section 4.6.19	7.41E+05	NA
Pu-238 ingrowth	Half-life equals 8.78E+01 years. See Section 4.6.13	6.74E+04	NA
Ra-226 ingrowth	Half-life equals 1.60E+03 years. See Section 4.6.16	4.30E+03	NA
Th-230 ingrowth	Half-life equals 7.70E+04 years.	1.08E+02	NA

4.6.13 Plutonium

All plutonium isotopes are anthropic and transuranic products of nuclear reactor operations or nuclear weapons production, deployment, and testing. Plutonium-238, Pu-239, and Pu-240 decay by the emission of alpha particles, have half-lives of 87.7, 2.41E+04, and 6.56E+03 years, respectively. Plutonium-241 decays by the emission of beta particles and has a 14.4-year half-life. Plutonium-239 and Pu-240 were identified in the IRA as COPCs primarily for the soil and crop ingestion pathway (Becker et al. 1998). Plutonium-238 was not identified as a COPC in the IRA (Becker et al. 1998) but was retained for analysis of isotopic ratios. The results for Pu-238, Pu-239, and Pu-240 are discussed in this section, along with plutonium isotopic ratios that are indicative of waste derived from weapons- or fuel-related disposals.

Plutonium-239 is often reported as Pu-239, Pu-239/240, or Pu-239+240. Any of the three reporting conventions is acceptable, but technically, it is most correct to report Pu-239 as either Pu-239/240 or Pu-239+240 because the individual isotopes cannot be chemically separated and they have alpha particle energies that are nearly identical. Therefore, it is nearly impossible to differentiate the isotopes in environmental samples using routine alpha spectroscopy. Nonradiochemical methods such as mass spectrometry must be applied to obtain results for each separate radionuclide.

Data analysis for WAG 7 includes evaluating the Pu-238:Pu-239/240 ratio when both plutonium isotopes are detected to determine if detected concentrations emanate from weapons-grade or reactor-grade plutonium. Concentrations of Pu-238 without Pu-239/240 or with a Pu-238:Pu-239/240 ratio of about 11 imply reactor-grade plutonium. Weapons-grade plutonium contains much more Pu-239/240 than Pu-238, with a Pu-238:Pu-239/240 ratio of approximately 0.02 to 0.03.

Comparison concentrations for the plutonium isotopes are presented in Table 4-53.

Table 4-53. Comparison concentrations for plutonium in groundwater and soils.

Contaminant	Surface Soil Background Concentration[a] (pCi/g)	Risk-Based Soil Concentration (pCi/g)	Aquifer Background Concentration (pCi/L)	Maximum Contaminant Level (pCi/L)	Risk-Based Aquifer Concentration[b] (pCi/L)
Plutonium-238	0.0049	29.2	0	15 (total alpha)	3.6
Plutonium-239	0.10[c]	28.8	0	15 (total alpha)	3.5
Plutonium-240	0.10[c]	28.8	0	15 (total alpha)	3.5

a. Soil background represents the 95% tolerance limit with 95% confidence for a composite soil sample (Rood, Hams, and White 1996).
b. Calculated risk-based concentration equivalent to an increased cancer risk of 1E-05d (Knobel, Orr, and Cecil 1992).
c. Result is for Pu-239/240 combined.

4.6.73.7 Waste Zone. Approximately 1.71E+04 Ci of Pu-238 were disposed of in the SDA. Table 4-54 identifies the waste streams containing the majority of Pu-238 activity. Approximately 6.48E+04 Ci of Pu-239 and 1.71E+04 Ci of Pu-240 were disposed of in the SDA. Tables 4-55 and 4-56 identify the waste streams containing the majority of Pu-239 and Pu-240 activity. All of the plutonium isotopes generate daughter products: Pu-238 decays to U-234, Th-230, Ra-226 and Pb-210; Pu-239 decays to U-235, Pa-231, and Ac-227; and Pu-240 decays to U-236, Th-232, and Ra-228. See the respective sections for individual daughter products to determine the relative contribution of plutonium decay to the daughter inventory.

Table 4-54. Waste streams containing plutonium-238.

Waste Stream Code or Generator	Waste Stream Description	Activity (Ci)	Proportion of Total Activity (%)
Idaho National Engineering and Environmental Laboratory (INEEL)	INEEL reactor operations waste.	1.46E+04	85.3
Miscellaneous	Miscellaneous minor streams.	6.50E+02	3.8
RFO-DOW-9H	Noncombustibles — gloveboxes, equipment, pumps, motors, control panels, and office equipment.	5.00E+02	2.9
TRA-603-9H	Expended fuel and ceramic fuel.	4.95E+02	2.9
RFO-DOW-3H	Uncemented sludge.	2.75E+02	1.6
RFO-DOW-6H	Filters.	2.32E+02	1.4
RFO-DOW-12H	Dirt, concrete, graphite, ash, and soot.	1.99E+02	1.2
RFO-DOW-4H	Combustibles — paper, rags, plastic clothing, cardboard, wood, and polyethylene bottles (Codes 330, 336, 337,900, and 970).	1.74E+02	1.0
Total Disposals		1.71E+04	100

Table 4-55. Waste streams containing plutonium-239.

Waste Stream	Waste Stream Description	Activity (Ci)	Proportion of Activity (%)
RFO-DOW-9H	**Noncombustibles—gloveboxes,** equipment, pumps, motors, control panels, and office equipment.	1.70E+04	26.3
RFO-DOW-3H	Uncemented sludge.	9.40E+03	14.5
RFO-DOW-6H	Filters.	7.90E+03	12.2
RFO-DOW-12H	Dirt, concrete, graphite, ash, and soot.	6.79E+03	10.5
RFO-DOW-4H	Combustibles—paper, rags, plastic clothing cardboard, wood, and polyethylene bottles.	5.96E+03	9.2
RFO-DOW-7H	Glass—including raschig rings.	5.37E+03	8.3
RFO-DOW-8H	Lead from glovebox gloves and sheeting.	4.53E+03	7.0
RFO-DOW-11H	Graphite molds.	3.37E+03	5.2
INEEL	Idaho National Engineering and Environmental Laboratory reactor operations waste.	1.29E+03	2.0
RFO-DOW-5H	Concrete and brick.	1.25E+03	1.9
Miscellaneous	Miscellaneous minor streams.	1.23E+03	1.9
RFO-DOW-13H	Resins.	7.31E+02	1.1
Total Disposals		6.48E+04	100

Table 4-56. Waste streams containing plutonium-240.

Waste Stream	Waste Stream Description	Activity (Ci)	Proportion of Activity (%)
RFO-DOW-9H	**Noncombustibles—gloveboxes,** equipment, pumps, motors, control panels, and office equipment.	3.85E+03	22.5
INEEL	Idaho National Engineering and Environmental Laboratory reactor operations waste.	2.36E+03	13.8
RFO-DOW-3H	Uncemented sludge.	2.12E+03	12.4
RFO-DOW-6H	Filters.	1.78E+03	10.4
RFO-DOW-12H	Dirt, concrete, graphite, ash, and soot.	1.53E+03	9.0
RFO-DOW-4H	Combustibles—paper, rags, plastic clothing, cardboard, wood, and polyethylene bottles (Codes 330,336,337,900, and 970).	1.35E+03	7.9
RFO-DOW-7H	Glass—including raschig rings.	1.21E+03	7.1
RFO-DOW-8H	Lead from glovebox gloves and sheeting.	1.02E+03	6.0
RFO-DOW-11H	Graphite molds.	7.62E+02	4.5
OFF-LRL-2H	Concrete, bricks, and asphalt.	4.53E+02	2.7
Miscellaneous	Miscellaneous.	3.42E+02	2.0
RFO-DOW-5H	Concrete and brick.	2.82E+02	1.7
Total Disposals		1.71E+04	100

Spectral gamma logging provided no data about Pu-238 or Pu-240, but detected Pu-239 based on the 414 keV gamma rays. Of the 135 probeholes logged using the spectral gamma logging tool, 100 (74%) showed the presence of Pu-239 above the noise level. Of the 4,863 total measurements collected from all probes at all depths, 1,261 (26%) showed the presence of Pu-239 above the noise level. The Pu-239 detection limit was approximately 29 nCi/g. The maximum and average observed Pu-239 levels were 194,171 nCi/g, and 2,246 nCi/g, respectively. The detection limit, maximum concentration, and average concentration are based on the assumption that Pu-239 is uniformly distributed in the vicinity of the measurement points.

4.6.13.2 Surface. A total of 186 soil samples were collected between 1994 and 2000 from around the RWMC. Based on gamma spectrometric analytic results, 76 samples were selected for Pu-238 and Pu-239/240 analysis. Five positive detections of Pu-238 were identified ranging from (5.1 ± 1.4)E-03 pCi/g at TSA (LMITCO 1995c) to (3.19 ± 0.53)E-02 pCi/g in the Pad A area (INEEL 2001). Fifty-nine positive detections of Pu-239/240 were identified, which ranged from (9.0 ± 2.0)E-03 pCi/g at SWEPP 5 (LMITCO 1996) to 1.22 ± 0.12 pCi/g at the active area (INEEL 2001).

A total of 124 vegetation samples were collected between 1990 and 2000 from the RWMC and control locations. Based on gamma spectrometric analytic results, about 30 samples were evaluated for Pu-238 and Pu-239/240. No positive detections of Pu-238 were identified; however seven positive detections of Pu-239/240 were identified. The positive detections of Pu-239/240 in vegetation samples ranged from (4.58 ± 0.15)E-04 pCi/g (INEEL 2000) to (1.0 ± 0.2)E-02 pCi/g (EG&G 1991).

A total of 210 surface run-off water samples were collected between 1991 and 2000 from the RWMC and control locations. Based on gamma spectrometric results, about 90 samples were evaluated for Pu-238 and Pu-239/240. No positive detections of Pu-238 were identified; however, eight positive detections of Pu-239/240 were identified. The positive detections of Pu-239/240 ranged from (2.04 ± 0.75)E-02 pCi/L (INEEL 2000) to (1.1 ± 0.3)E-01 pCi/L (LMITCO 1995c).

4.6.13.3 Vadose Zone Core Samples. The distributions of plutonium in vadose zone core, soil moisture, and perched water in the various depth intervals are discussed below.

4.6.13.3.1 Plutonium-238 in Vadose Zone Core Samples—A total of 341 vadose zone core samples collected during well drilling were analyzed for Pu-238 between 1971 and 2000. Eighteen positive detections were identified with 13 above the INEEL surface soil background of 0.0049 pCi/g. Four of the 13 samples above background were analyzed in 1972 and the data are of questionable quality because of cross-contamination concerns. All positive detections are listed in Table 4-57.

A summary of the occurrence of Pu-238 detections by depth interval is shown in Table 4-58. The majority of valid Pu-238 detections (i.e., those not taken between 1971 and 1974) are located in the Pad A and Pit 5 areas (i.e., Wells D02 and TW1).

Table 4-57. Positive detections of plutonium-238 in vadose zone core samples.

Borehole Identification	Sample Depth (ft)	Concentration ± 1σ (pCi/g)	Date
78-5	101.7	0.0031 ± 0.0010	1978
USGS-93	101.0 to 103.0	0.0076 ± 0.0015[a]	1972
	103.0 to 105.0	0.014 ± 0.003[a]	1972
USGS-96	100.5 to 101.0	0.0059 ± 0.0015[a]	1972
	110.0 to 112.9	0.009 ± 0.002[a]	1972
D02	1.2 to 1.7	0.26 ± 0.02	1987
	15.5 to 16.0	0.0149 ± 0.0018	1987
	229.7 to 230.0	0.0024 ± 0.0007	1987
	230.0 to 230.3	0.0065 ± 0.0019	1987
	230.0 to 230.3	0.0322 ± 0.0017	1987
	230.0 to 230.3	0.0015 ± 0.0004	1987
	230.0 to 230.3	0.0033 ± 0.0006	1987
TW1	101.0 to 101.2	0.017 ± 0.002	1987
	101.0 to 101.2	0.0118 ± 0.0017	1987
	101.2	0.0046 ± 0.0014	1987
	101.2	0.0063 ± 0.0017	1987
	101.2	0.0065 ± 0.0016	1987
	101.2	0.010 ± 0.003	1987

a. The 1971 and 1972 data must be used with discretion. They are questionable because of cross-contamination concerns (see Section 4.5.5).

Table 4-58. Summary of plutonium-238 occurrences in the vadose zone core samples.

Depth Interval (ft)	Number of Pu-238 Detections/Total Number of Samples (%)	Range (pCi/g)	Cores with Detections
0 to 35	2/33 (6.1)	0.0149 to 0.26	D02
35 to 140	11/140 (7.8)	0.0031 to 0.017	78-5, TW-1, USGS-93, USGS-96
140 to 250	5/157 (3.2)	0.0015 to 0.033	D02
Greater than 250	0/11 (0)	Not applicable	None

4.6.13.3.2 Plutonium-239/240 in Vadose Zone Core Samples—A total of 352 vadose zone core samples collected during well drilling were analyzed for Pu-239/240 between 197I and 2000. Twenty-nine positive detections were identified; however, nine of those were suspect because of well drilling and sampling methods used in the early 1970s (see Section 4.5.5). The samples with detected concentrations of Pu-239/240 are listed in Table 4-59.

Table 4-59. Positive detections of plutonium-239/240 in vadose zone core samples.

Borehole Identification	Sample Depth (ft)	Concentration ± 1σ (pCi/g)	Date
76-3	97.5 to 97.8	0.017 ± 0.005	1976
78-5	240.3	0.013 ± 0.002	1978
79-2	99.1 to 99.9	0.061 ± 0.004	1979
	99.1 to 99.9	0.056 ± 0.004	1979
	99.9 to 101.7	0.034 ± 0.003	1979
	99.9 to 101.7	0.037 ± 0.003	1979
	101.7 to 103.0	0.038 ± 0.003	1979
	101.7 to 103.0	0.036 ± 0.003	1979
I-3S	100.0	0.009 ± 0.003	1999
USGS-87	231.2 to 233.0	0.029 ± 0.004[a]	1971
USGS-88	521.0 to 522.0	0.022 ± 0.003[a]	1971
USGS-91	7.83 to 8.92	0.026 ± 0.005[a]	1972
	236.5 to 237.0	0.140 ± 0.007[a]	1972
USGS-93	98.0 to 101.0	0.110 ± 0.007[a]	1972
	101.0 to 103.0	0.230 ± 0.011[a]	1972
	101.0 to 103.0	0.540 ± 0.012[a]	1972
	103.0 to 105.0	0.081 ± 0.011[a]	1972
USGS-96	100.5 to 101.0	0.045 ± 0.002[a]	1972
D02	1.2 to 1.7	1.13 ± 0.05	1987
	15.5 to 16.0	0.255 ± 0.009	1987
	230.0 to 230.3	0.058 ± 0.002	1987
TW1	101.0 to 101.2	0.74 ± 0.04	1987
	101.0 to 101.2	0.61 ± 0.03	1987
	101.2	0.197 k0.013	1987
	101.2	0.190 ± 0.013	1987
	101.2	0.200 ± 0.013	1987
	101.2	0.168 ± 0.009	1987
	101.2	0.170 ± 0.009	1987
	101.2	0.178 ± 0.013	1987

a. The 1971 and 1972 data must be used with discretion. They are questionable because of **cross-contamination concerns (*see* Section 4.5.5).**

Table 4-60 shows the number of cores sampled and the number of cores in which Pu-239/240 was detected by depth interval. The occurrence of Pu-239/240 in depth intervals is consistent with the pattern of Pu-238 detections in Wells USGS-93, USGS-96, D02, and TW1.

Most (i.e., 21) detections were observed in close proximity to the **B-C** interbed, though many of those analyses were duplicate samples. Detections at the B-C interbed depth are concentrated primarily in two areas in the SDA; near Pit 5 (Boreholes 79-2, D02 and TW1) and the west end of the SDA (i.e., Well 76-3, USGS-93, and USGS-96).

Two detections were identified in the shallow surficial sediments (one near Pit 5 and the other near Pit 14), and four near the C-D interbed (also near Pit 5 and Pit 14 plus two outside the SDA). Well USGS -88 (south of the SDA) had detectable concentrations of Pu-239/240 at 520 ft. Plutonium-239/240 detections in Boreholes TW1 and D02 are corroborated **by** detections of Pu-238 and Am-241.

Table 4-60. Summary of plutonium-239/240 occurrences in vadose zone core samples.

Depth Interval (ft)	Number of Pu-239/240 Detections/Total Number of Core Samples (%)	Range (pCi/g)	Cores with Detections
0 to 35	3/37 (8.1)	0.026 to 1.13	D02, USGS-91
35 to 140	21/147 (14.3)	0.009 to 0.74	76-3, 79-2, I-3S, USGS-93, USGS-96, TW1
140 to 250	4/157 (2.5)	0.013 to 0.14	78-5, D02, USGS-87, USGS-91
>250	1/11 (9.0)	0.022	USGS-88

4.6.13.3.3 Plutonium Ratios in Vadose Zone Core Samples — When a sample contains both Pu-238 and Pu-239/240, the ratio of Pu-238:Pu-239/240 can be an indicator of whether the waste source was originally reactor operations or weapons manufacturing. In general, activity ratios around 0.02 to 0.03 are indicative that the plutonium in the sample originated from weapons manufacturing waste, and activity ratios around 11 are indicative that the waste source was reactor operations. A sample with Pu-238 but no detectable Pu-239/240 is usually indicative of waste from reactor operations. A sample with Pu-239/240 but no Pu-238 is indicative of weapons-related waste.

For the RWMC core samples, most plutonium detections and ratios suggest that the plutonium detections are predominantly from weapons manufacturing waste (see Table 4-61). However, some detections and ratios also indicate the presence of plutonium from reactor operations such as samples from Well D02 at the 230-ft depth. Nearby core samples from Wells TW1 and 79-2 at approximately 100-ft depth show evidence of weapons manufacturing waste.

Table 4-61. Detections of plutonium-238, plutonium-239/240, and plutonium-238:plutonium-239/240 activity ratios for vadose zone core samples.

Borehole Identification	Pu-238 (pCi/g)	Pu-239/240 (pCi/g)	Pu-238: Pu-239/240 Activity Ratio	Probable Waste-Generating Process	Sample Depth (ft)	Date
76-3	Analyzed for but not detected (ND)	0.017	Not applicable (NA)	Weapons[a]	97.5 to 97.8	1976
78-5	0.0031	ND	NA	Reactors[b]	101.7	1978
78-5	ND	0.013	NA	Weapons[a]	240.3	1978
79-2	ND	0.061	NA	Weapons[a]	99.1 to 99.9	1979
79-2	ND	0.056	NA	Weapons[a]	99.1 to 99.9	1979
79-2	ND	0.034	NA	Weapons[a]	99.9 to 101.7	1979
79-2	ND	0.037	NA	Weapons[a]	99.9 to 101.7	1979
79-2	ND	0.038	NA	Weapons[a]	101.7 to 103.0	1979
79-2	ND	0.036	NA	Weapons[a]	101.7 to 103.0	1979
USGS-87	ND	0.029'	NA	Weapons[a,c]	231.2 to 233.0	1971
USGS-88	ND	0.022[c]	NA	Weapons[a,c]	521.0 to 522.0	1971

Table 4-61. (continued).

Borehole Identification	Pu-238 (pCi/g)	Pu-239/240 (pCi/g)	Pu-238: Pu-239/240 Activity Ratio	Probable Waste-Generating Process	Sample Depth (ft)	Date
USGS-91	ND	0.026[c]	NA	Weapons[a,c]	7.83 to 8.92	1972
USGS-91	ND	0.140[c]	NA	Weapons[a,c]	236.5 to 237.0	1972
USGS-93	0.0076[c]	0.110[c]	0.069	Weapons[a,c]	98 to 101	1972
USGS-93	ND	0.230[c]	NA	Weapons[a,c]	101 to 103	1972
USGS-93	0.014[c]	0.540[c]	0.026	Weapons[a,c]	101 to 103	1972
USGS-93	ND	0.081[c]	NA	Weapons[a,c]	103 to 105	1972
USGS-96	0.0059[c]	0.045[c]	0.131	Indeterminate'	100.5 to 101.0	1972
USGS-96	0.009[c]	ND	NA	Reactors[b,c]	110.0 to 112.9	1972
D02	0.26	1.13	0.230	Indeterminate	1.2 to 1.7	1987
D02	0.0149	0.255	0.058	Weapons[a]	15.5 to 16.0	1987
D02	0.0024	ND	NA	Reactors[b]	229.7 to 230.0	1987
D02	0.0065	ND	NA	Reactors[b]	230.0 to 230.3	1987
D02	0.0322	0.058	0.555	Indeterminate	230.0 to 230.3	1987
D02	0.0015	ND	NA	Reactors[b]	230.0 to 230.3	1987
D02	0.0033	ND	**NA**	Reactors[b]	230.0 to 230.3	1987
TW1	0.017	0.74	0.023	Weapons[a]	101 to 101.2	1987
TW1	0.0118	0.61	0.019	Weapons[a]	101 to 101.2	1987
TW1	0.0046	0.197	0.023	Weapons[a]	101.2	1987
TW1	0.0063	0.190	0.033	Weapons[a]	101.2	1987
TW1	0.0065	0.200	0.033	Weapons[a]	101.2	1987
TW1	ND	0.168	NA	Weapons[a]	101.2	1987
TW1	ND	0.170	NA	Weapons[a]	101.2	1987
TW1	0.010	0.178	0.056	Weapons[a]	101.2	1987

a. Positive Pu-239/240 detections, without detections of Pu-238, are indicative of weapons (i.e., manufacturing waste or fallout). The Pu-238: Pu-239/240 ratio for weapons manufacturing waste is 0.02 to 0.03.
b. Positive Pu-238 detections without detections of Pu-239/240 are indicative of high bumup reactor fuel and fuel processing waste. The Pu-238 activity in high burnup reactor fuel and fuel processing waste is approximately 11 times higher than the Pu-239/240 activity. Thus, the Pu-238:Pu-239/240 ratio for fuel is approximately 11. In many cases presented in this table, the concentration of expected Pu-239/240 would be too low to detect.
c. The 1971 and 1972 data must be used with discretion. They are questionable because of cross-contamination concerns (see Section 4.5.5).

4.6.13.3.4 Summary ***of*** Plutonium in Vadose Zone Core Samples — Plutonium was detected infrequently in core samples, with detection rates of 5.3% for Pu-238 and 8.2% for Pu-239/240. The detections are very low level, ranging from two to four orders of magnitude below the soil 1E-05 RBC. Generally, detections do not occur contiguously throughout the depth of a core, but occur sporadically or are concentrated at one depth interval.

A cluster of Pu-238 and Pu-239/240 detections exists in the Pad A and Pit **5** area, especially around the B-C interbed. These detections include the following:

- **Numerous** detections of Pu-238 and Pu-239/240 in Well TW1 near Pit **5** around **the** 100-ft depth. with **no** detections in **the** numerous samples from **the** 225 **to** 227-ft depth.

- Detectable Pu-239/240 with no Pu-238 **at** three different depth intervals, concentrated between 99.1 and 103 ft, with no detections in the 28-, 70- **or** 230-ft depths.

- Detectable Pu-238 and Pu-239/240 in shallow (less than 15 ft) and deep (230 ft) samples from Well D02 near Pit 5. **No** samples were collected from the 100-ft depth interval **of** Well D02.

Plutonium activity ratios calculated *on* **the** core samples most often suggest ***that*** the waste **source originated** from weapons manufacturing rather than **reactor** operations, though **some** samples are suggestive **of reactor** fuel. Where ratios were **interpreted** as reactor-related waste, the interpretation was **founded** on no detectable Pu-239/240, **rather** than **because** the **ratio** was greater than the indicator value **of** 11.

4.6.13.3.5 Plutonium-238 In Shallow Lysimeter Samples—A total of 105 shallow lysimeter samples were analyzed for Pu-238 between 1997 and May 2001, with seven positive detections (see **Table** 4-62). Four **of** the detections were greater than the 1E-05 aquifer RBC of 3.6 **pCi/L**. The aquifer RBC **does** not apply to lysimeter samples, but is **used** only for a basis **of** comparison. Five **of** the seven samples that **exceeded** the aquifer RBC occurred near Pad A **and** Pit 5. **The** PA prefix on the lysimeter name indicates a Pad A lysimeter. ***Of*** the five detections near Pad A, the three samples from Lysimeters PA01 and PA02 were reanalyzed and detections **were** not confirmed. **The two** samples containing detectabk amounts **of** Pu-238 in Lysimeter PA03 were not reanalyzed **because** of insufficient sample volume. **The** occurrence of the Pu-238 detections in shallow lysimeter samples is shown in Figure 4–28.

Table 4–62. Detected concentrations of plutonium-238 in shallow lysimeters.

Lysimeter	Depth (ft)	Concentration ± 1σ (pCi/L)	Confirmation Flag.[a]	Date
PA01-L15	14.3	**9 ± 2**	B	April 1998
		2.3 ± 0.7	B	September 2000
PA02-L16	8.7	**37 ± 0.4**	B	December 2000
PA03-L33	10	**24 ± 2**	A	August 1997
		2.2 ± 0.5	A	February 1998
98-4L38 (SDA-08)	17	[illegible]	B	September 2000
98-5L39 (SDA-10)	10.5	**5.6 ± 1.6**	B	April 1998

a Confirmation flag:
A = No second sample collected, no reanalysis performed.
B = Reanalysis performed, no confirmation.
Note. Values in **red bold** indicate that the concentration exceeds the 1E-05 aquifer risk-based concentration (RBC) of 3.6 pCi/L for Pu-238. The RBCs for the aquifer do not apply to *soil* moisture samples, but are used here as a basis of comparison

Year	Quarter	98-1 L35	98-4 L38	98-5 L39	PA01-L15	PA02-L16	PA03-L33	W06-L27	W08-L13	W08-L14	W23-L08	W23-L09	W25-L28
1997	1												
	2												
	3						24						
	4												
1998	1						2.2						
	2			5.6	9								
	3												
	4												
1999	1												
	2												
	3												
	4												
2000	1												
	2												
	3		0.9		2.3								
	4					3.7							
2001	1												
	2												
	3												
	4												

Key	
(green)	Analysis was performed for Pu-238, but none was detected.
(pink)	Pu-238 was detected (pCi/L).
	If more than one detection occurred in a Well in a single quarter, only the highest concentration is listed.

Figure 4-28. Occurrence of plutonium-238 in shallow lysimeter samples (detected concentrations in pink).

Four of the seven positive Pu-238 detections were greater than the aquifer RBC. The ceramic cup of the lysimeter may filter plutonium and bias the measurement low (see Section 4.5.6); therefore, the Pu-238 measured in the lysimeter samples may not be representative of the actual soil moisture concentrations.

A Pu-238 trend might be developing in Lysimeter PAM-L16. All but one of the Pu-238 values in this lysimeter are nondetections, but an observable increase has been observed in their concentrations over time. There was a statistical detection result greater than 2σ but less than 3σ in September 2000 and a positive detection in December 2000.

The August 1997 sample from Lysimeter PA03-L33 exceeded the aquifer RBC of 3.6 pCi/L. The next sample taken from Lysimeter PA03-L33 (February 1998) contained detectable amounts of Pu-238. but five subsequent samples pulled from that lysimeter-well (April and December, 1998; May and November 1999; and March 2000) did not contain detectable Pu-238 (*see* Figure 4-29). Ultra low-level thermal ionization mass spectrometry (TIMS) analysis did not confirm the presence of Pu-238 above 0.002 pCi/L in PA03-L33 or any other shallow lysimeter well (*see* Section 4.6.14).

4.6.13.3.6 Plutonium-239/240 In Shallow Lysimeter Samples—A total of 107 shallow lysimeter well samples were analyzed for Pu-239/240 between 1997 and May 2001, resulting in one positive detection. The positive sample came from Lysimeter PA02-L16 in December 2000 and had a concentration of 0.70 ± 0.17 pCi/L. The positive result was not confirmed by reanalysis of the original sample. The occurrence of the positive Pu-239/240 detection relative to the other shallow lysimeter sampling events is shown in Figure 4-29.

The plutonium may be filtered out of the sample by the ceramic cup of the lysimeter (see Section 4.5.6), and the Pu-239/240 measured in the lysimeter samples may not be representative of the actual soil moisture concentrations.

Year	Quarter	98-1 L35	98-4 L38	98-5 L39	PA01-L15	PA02-L16	PA03-L33	W06-L27	W08-L13	W08-L14	W23-L08	W23-L09	W25-L28
1997	1												
	2												
	3												
	4												
1998	1												
	2												
	3												
	4												
1999	1												
	2												
	3												
	4												
2000	1												
	2												
	3												
	4					0.7							
2001	1												
	2												
	3												
	4												
Key		Analysis was performed for Pu-239/240, but none was detected.											
		Pu-239/240 was detected (pCi/L).											
		If more than one detection occurred in a well in a single quarter, only the highest concentration is listed.											

Figure 4-29. Occurrence of plutonium-239/240 detections in shallow lysimeters.

4.6.13.3.7 Plutonium Ratios in Shallow Lysimeter Samples—When a sample contains both Pu-238 and Pu-239/240, the ratio of Pu-238:Pu-239/240 can be an indicator of whether the waste source was originally reactor operations or weapons manufacture. In general, activity ratios around 0.02 to 0.03 are indicative that the plutonium in the sample originated from weapons manufacturing waste, and activity ratios around 1:1 are indicative that the waste source was reactor operations. A sample with Pu-238 but no detectable Pu-239/240 is usually indicative of waste from reactor operations. A sample with Pu-239/240 but no Pu-238 is indicative of weapons-related waste.

All plutonium detections and ratios associated with shallow soil moisture sample analysis indicate the plutonium detections are from high burnup reactor-related waste and not weapons manufacturing waste (see Table 4-63). The lysimeter wells showing reactor-generated plutonium (Wells PA01, PA02 and PA03) are located near Pad A and Pit 5. Soil moisture samples from these same lysimeters also show elevated levels of uranium. A single, low-level Pu-238 detection was identified that is associated with Well 98-4. Well 98-5 at the west end of the SDA also yielded a single detection; however, it contained a supporting Pu-239/240 detection with a ratio that suggests plutonium in this soil moisture sample is likely from reactor operations.

Table 4-63. Detections of plutonium and plutonium-238:plutonium-239/240 activity ratios associated with positive detections from the same shallow lysimeter samples.

Lysimeter	Pu-238 (pCi/L)	Pu-239/240 (pCi/L)	Pu-238: Pu-239/240 Activity Ratio	Probable Waste-Generating Process	Date
98-4L38	0.9	Analyzed for but not detected (ND)	Not applicable (NA)	Reactors[a]	September 2000
98-5L39	5.6	ND	NA	Reactors[a]	April 1998
PA01-L15	9	ND	NA	Reactors[a]	April 1998
PA01-L15	2.3	ND	NA	Reactors[a]	September 2000
PA02-L16	3.7	0.7	5.3	Reactors[a]	December 2000
PA03-L33	24	ND	NA	Reactors[a]	August 1997
PA03-L33	2.2	ND	NA	Reactors[a]	February 1998

a. Positive Pu-238 detections without accompanying detections of Pu-239/240 are indicative of high burnup reactor fuel and fuel processing waste. The Pu-238 activity in high burnup reactor fuel and fuel processing waste **is** approximately 11 times higher than the Pu-239/240 activity. Thus, the Pu-238:Pu-239/240 ratio for reactor operations is approximately 11.

4.6.13.3.8 Summary ***of*** Plutonium in Shallow Lysimeter ***Samples***—Plutonium detections are sporadic in shallow lysimeter samples. The detection rate was 6.7% for Pu-238 and 0.9% for Pu-239/240. Five of the seven Pu-238 detections occurred around Pad A and Pit 5. The only Pu-239/240 detection also occurred near Pad A. The ratios associated with shallow soil moisture sample analysis suggest that the plutonium detections are from high burnup reactor-related waste and not weapons manufacturing waste.

4.6.13.4 Lysimeter Samples at Depths *of* 35 to 140 *ft*

4.6.13.4.1 Plutonium-238 in Intermediate-Depth Lysimeter Samples — A total of 40 samples from 13 lysimeters in the 35 to 140-ft depth interval were analyzed for Pu-238 between 1997 and May 2001, with three positive detections (see Table 4-64). One of these was greater than the 1E-05 aquifer RBC of 3.6 pCi/L. The detections are shown in Figure 4-30.

All positive detections occurred in the August 1997 sampling round. The positive sample results could not be confirmed by reanalysis because available sample volumes were limited. Subsequent samples collected from these three wells (through May 2001) have not contained detectable levels of Pu-238.

Yr	Quarter	D06-DL01	D06-DL02	D15-DL06	I-1S	I-2S	I-3S	I-4S	I-5S	O-2S	O-3S	O-4S	O-5S	TW1-DL04
1997	1													
	2													
	3	11.6	3.3	3.1										
	4													
1998	1													
	2													
	3													
	4													
1999	1													
	2													
	3													
	4													
2000	1													
	2													
	3													
	4													
2001	1													
	2													
	3													
	4													
Key		Analysis was performed for Pu-238, but none was detected.												
		Pu-238 was detected (pCi/L).												
		If more than one detection occurred in a well in a single quarter, only the highest concentration is listed.												

Figure 4-30. Occurrence of detectable plutonium-238 (in pink) in lysimeter samples from the 35 to 140-ft depth interval.

Table 4-64. Positive detections of plutonium-238 in the vadose zone samples from 35 to 140-ft depth interval.

Lysimeter	Depth (ft)	Concentration ± 1σ (pCi/L)	Confirmation Flag[a]	Date
D06-DL01	88	**11.6 ± 1.8**	A	August 1997
D06-DL02	44	3.3 ± 0.6	A	August 1997
D15-DL06	98	3.1 ± 0.7	A	August 1997

a. Confirmation flag:
A = No second sample collected, no reanalysis performed.

Note: Values **in red bold** indicate that the concentration exceeds the 1E-05 aquifer risk-based concentration (RBC) of 3.6 pCi/L. The RBCs for the aquifer do not apply to soil moisture samples, but are used here as a basis of comparison.

The detection in Lysimeter D06-DL01 exceeded the aquifer 1E-05 RBC, but no detectable concentrations have been measured in this lysimeter since 1998. However, the plutonium may be filtered out of the sample by the ceramic cup of the lysimeter (see Section 4.5.6), and the Pu-238 measured in the lysimeter samples may not be representative of the actual soil moisture concentrations.

4.6.13.4.2 ***Plutonium-239/240* In Intermediate-Depth *Lysimeter* Samples**— A total of 39 lysimeter samples from the 35 to 140-ft depth interval were analyzed by the INEEL for Pu-239/240 between 1997 and May 2001, with three positive detections (see Table 4-65). The occurrence of these detections is shown graphically in Figure 4-31.

Table 4-65. Plutonium-239/240 detections in lysimeters from the 35 to 140-ft depth interval of the vadose zone.

Lysimeter	Depth (ft)	Concentration ± 1σ (pCi/L)	Confiition Flag[a]	Date
TW1-DL04	101.7	0.34 ± 0.09	A	November 1998
D15-DL06	98	1.1 f 0.3	A	August 1997
O4S-DL24	98	3.3 ± 1.0	B	December 2000

a. Confirmation flag:
A = No second sample collected, no reanalysis performed.
B = Reanalysis performed, no confirmation.

Yr	Quarter	D06-DL01	D06-DL02	D15-DL06	I-1S	I-3S	I-4S	I-5S	O-2S	O-3S	O-4S	O-5S	TW1-DL04
1997	1												
	2												
	3			1.1									
	4												
1998	1												
	2												
	3												
	4												0.34
1999	1												
	2												
	3												
	4												
2000	1												
	2												
	3												
	4										3.3		
2001	1												
	2												
	3												
	4												

Key	
	Analysis was performed for Pu-239/240, but none was detected.
	Pu-239/240 was detected (pCi/L).
	If more than one detection occurred in a well in a single quarter, only the highest concentration is Listed.

Figure 4-31. Occurrence of plutonium-239/240 detections in lysimeter samples from 35 to 140-ft deep. Pink indicates a detected concentration.

The positive sample results were all less than the aquifer RBC and were not confirmed by reanalysis. Subsequent samples collected from these three wells (through May 2001) have not contained detectable Pu-239/240.

Some of the lysimeter samples analyzed using TIMS indicated that samples from Lysimeter TW1-DL04 may contain PU-239. This is discussed more in Section 4.6.14.

The detected concentrations of Pu-239/240 in lysimeter samples are less than the aquifer RBC of 3.5 pCi/L. However, the plutonium may be filtered out of the sample by the ceramic cup of the lysimeter (see Section 4.5.6), and the Pu-239/240 measured in the lysimeter samples may not be representative of the actual soil moisture concentrations.

4.6.13.4.3 Plutonium Ratios in Intermediate-Depth Lysimeter Samples—Most plutonium detections and ratios associated with the intermediate-depth soil moisture sample analyses indicate the plutonium detections are from both weapons manufacturing waste and reactor fuel (see Table 4-66). Wells D06 and TW1 are located near each other, yet their ratios indicate different waste sources. This inconclusive information may be associated with variability in sample concentrations near the detection limit.

Table 4-66. Detections of plutonium-238 and plutonium-239/240, and the plutonium-238: 239/240 activity ratios for intermediate-depth lysimeter samples.

Lysimeter	Pu-238 (pCi/L)	Pu-239/240 (pCi/L)	Pu-238: Pu-239/240 Activity Ratio	Possible Waste Source	Sample Depth (ft)	Date
D06-DL01	11.6	Analyzed for but not detected (ND)	Not applicable (NA)	Reactors[a]	36 to 140	08/1997
D06-DL02	3.3	ND	NA	Reactors[a]	36 to 140	08/1997
D15-DL06	3.1	1.1	2.8	Indeterminate	36 to 140	08/1997
O4S-DL24	ND	3.31	NA	Weapons[b]	36 to 140	12/2000
TW1-DL04	ND	0.34	NA	Weapons[b]	36 to 140	11/1998

a. Positive Pu-239/240 detections, without detections of Pu-238, are indicative of weapons (i.e., manufacturing waste or fallout). The Pu-239/240 activity in weapons manufacturing waste is approximately 40 times higher than the Pu-238 activity. Therefore, the Pu-238:Pu-239/240 ratio for weapons manufacturing waste is 0.02 to 0.03, whereas the Pu-238:Pu-239/240 ratio for fallout is approximately 0.03 to 0.06.

b. Positive Pu-238 detections without detections of Pu-239/240 are indicative of high bumup reactor fuel and fuel processing waste. The Pu-238 activity in high bumup reactor fuel and fuel processing waste is approximately 11 times higher than the Pu-239/240 activity. Therefore, the Pu-238:Pu-239/240 ratio for fuel is approximately 11. In many cases presented in this table, the concentration of expected Pu-239/240 would be too low to detect.

4.6.13.4.4 Summary of Plutonium in Intermediate-Depth Lysimeter Samples— Plutonium occurs sporadically in the intermediate-depth lysimeters. Detection rates in the routine monitoring samples were 7.5% for Pu-238 and 7.7% for Pu-239/240. However, the plutonium may be filtered out of the sample by the ceramic cup of the lysimeter (see Section 4.5.6), and the Pu-239/240 measured in the lysimeter samples may not be representative of the actual soil moisture concentrations.

Two noteworthy trends were identified in the plutonium data, as follows:

- Detectable concentrations of Pu-238 occurred in lysimeters at the 44- and 88-ft depths in Well D06 in the August 1997 sampling
- Plutonium-239/240 was detected in core TW1 (i.e., 101 to 101.2 ft), and later in Lysimeter TW1-DL04 (i.e., 101.7 ft).

Otherwise, no other trends are notable. In Well D06 lysimeters, positive detections have not occurred in the three sampling events subsequent to the August 1997 detections. Plutonium ratios in the intermediate-depth lysimeters are indicative of both weapons- and reactor-related waste.

4.6.13.5 Deep Lysimeter and Perched Watar Samples at Depths Greater than 140 ft

4.6.13.5.1 Plutonium-238 in Deep Lysimeter and Perched Water Samples—The USGS and INEEL jointly sample perched Well USGS-92. A total of 56 water samples and nine filtered sediment samples from the deep suction lysimeters and perched water wells were analyzed for Pu-238 by the USGS and INEEL between 1972 and December 2000. Three positive detections were identified (see Table 4-67). One of the samples exceeded the 1E-05 RBC for the aquifer.

Table 4-67. Positive detections of plutonium-238 from lysimeters and perched water wells.

Lysimeter or Well	Depth (ft)	Concentration ± 1σ (pCi/L) Water	Continnation Flag'	Concentration ± lo (pCi/g) Filtered Sediments	Confirmation Flag'	Date
USGS-92	214	0.025 ± 0.008[b]	None	Not analyzed (NA)	None	May 1974
		0.39 ± 0.05	None	NA	None	November 1994
		NA	None	1.4 ± 0.3	A	April 1997
		4.8 ± 1.0	B	NA	None	December 2000

a. Confirmation flag:
A = No second sample collected, no reanalysis performed.
B = Reanalysis performed, no confirmation.
b. The 1972 to 1914 data must be used with discretion. They are questionable because of cross-contamination concerns.
Note: Values in **red bold** indicate that the concentration exceeds the 1E-05 aquifer risk-based concentrati'on (RBC) of 3.6 pCi/L for Pu-238.

Subsequent water samples collected from Well USGS-92 (through December 2000) have not contained detectable Pu-238. The reanalysis result of the December 2000 water sample was a nondetect. A questionable Pu-238 detection was identified in May 1974. Detections associated with USGS wells between 1972 and 1974 are known to be suspect and questionable because of cross-contamination problems associated with early well drilling and well construction techniques and the types of sampling methodology employed at that time (Barraclough et al. 1976) (see Section 4.5.7).

Perched water samples are filtered because they typically contain sediments. Some filtered fractions also were analyzed for Pu-238. The filtered fraction from one sample had a detection of Pu-238 but could not be confirmed by reanalysis because of limited sample volume.

Plutonium in the perched water samples collected with the bailer (e.g., Well USGS-92 or 88021)) is not subject to sorption by the ceramic filter because there is no porous cup involved.

***4.6.13.5.2 Plutonium-239/240* in Deep Lysimeter and Perched Water Samples**—A total of 56 water samples and nine filtered sediment samples from the deep suction lysimeters and perched water wells were analyzed for Pu-239/240 by the USGS and WAG 7 between 1972 and December 2000. Two positive detections were identified, neither of which exceeded the aquifer RBC of 3.5 pCi/L (see Table 4-68).

Table 4-68. Positive detections of plutonium-239/240 from lysimeters and perched water wells.

Lysimeter or Well	Depth (ft)	Concentration ± 1σ (pCi/L) Water	Confirmation Flag"	Concentration ± 1σ (pCi/g) Filtered Sediments	Confirmation Flag"	Date
USGS-92	214	Not analyzed (NA)	None	0.32 ± 0.06	B	February 1998
O6D-DL26	225	2.1 ± 0.6	None	NA	A	June 2000

a. Confirmation flag:
A = No second sample collected, no reanalysis performed.
B = Reanalysis performed, no confirmation.

Perched water samples are filtered because they typically contain sediments. The filtered fractions also are analyzed for Pu-239/240. Two separate samples were collected from Well USGS-92 in February 1998 and filtered, and the positive sediment sample result was not confirmed by reanalysis of the duplicate sample. The USGS and INEEL jointly sample perched water from Well USGS-92; however, the other RWMC perched wells and lysimeters are the responsibility of the INEEL.

Subsequent water samples collected from perched Well USGS-92 and lysimeter Well 06D (through December 2000) have not contained detectable amounts of Pu-239/240. The positive water sample result from Well 06D could not be confirmed by reanalysis of the original sample because the volume of water collected was insufficient to perform the analysis.

Plutonium may be filtered out of the sample by the ceramic cup of the lysimeter (see Section 4.5.6), and the Pu-239/240 measured in the lysimeter samples may not be representative of the actual soil moisture concentrations. However, perched water samples collected with the bailer (e.g., Well USGS-92 or 8802D) are not subject to ceramic filtering because no porous cup is involved. Ultra low-level Pu-239 and Pu-240 analyses using TIMS were conducted on some perched water samples to verify the presence of plutonium. The results are presented in Section 4.6.14. The TIMS results for perched Well 8802D justify continued observation, but no conclusions can be drawn based on the limited data set.

***4.6.13.5.3* Plutonium Ratios in Deep Lysimeter and Perched Water Samples**—The plutonium detections and ratios associated with the deep lysimeter and perched water sample analyses indicate the plutonium originates from both weapons manufacturing waste and reactor operations (see Table 4-69). A single, low-level Pu-239/240 detection associated with lysimeter Well 06D was identified; however, it is premature to conclude that the Pu-239/240 detected in this well is from weapons without additional radioanalytical data. It is interesting to note that the two perched water sample results from Well USGS-92 are indicative of reactor operations, whereas a filtered sediment sample, from a different Well-USGS-92 sample indicates weapons waste. Most likely, the conflicting indications are associated with analytical error near the detection limit.